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# (54) SURFACE-COATED HARD MEMBER FOR CUTTING AND ABRASION-RESISTANT TOOLS.

(57) A surface-coated superhard member for a cutting or abrasion-resistant tool, wherein a coating is disposed on the surface of a parent metal for the tool so as to improve the abrasion resistance thereof. This member comprises a parent metal and, superimposed on the surface thereof, a hard coating having a thickness of 0.5 to 10 µm and comprising at least one member selected from among a carbide, a nitride and a carbonitride of $M_{1-x}Al_x$ (wherein $0 \leq x \leq 0.5$), the M to Al ratio of which is continuously or stepwise changed from M (wherein M represents Ti, Zr or Hf) at the interface of the parent metal and the coating to MAl at the surface of the coating opposite to the parent metal. This structure effectively utilizes the characteristic properties of metals M and Al.

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Technical Field of The Invention

This invention relates to a surface-coated hard material for cutting tools or wear resistance tools, in which a coating layer is provided on the surface of a base material of a cutting tool or wear resistance tool to improve the wear reistance.

Technical Background

Up to the present time, cutting tools and wear resistance tools have generally been composed of cemented carbides based on tungsten carbide (WC), various cermets based on titanium carbide (TiC), steels such as high-speed steels or hard alloys and ceramics based on silicon carbide and silicon nitride.

In order to improve the wear resistnace of the cutting tools or wear resistance tools, a surface-coated hard material has been developed and has lately been put to practical use, in which one or more layers of carbides, nitrides or carbonitrides of Ti, Hf or Zr or oxide of Al are formed, as hard coating layers, on the surface of the hard material by a PVD method or CVD method. In particular, the hard coating layer formed by the PVD method is capable of improving the wear resistnce without deteriorating the strength of the base material and accordingly, it is suitable for a cutting use requiring a strength, for example, throwaway inserts for drills, end mills, milling cutters, etc.

However, the PVD method is favorably comapred with the CVD method in respect of that the hard coating layer can be formed without deteriorating the strength of the substrate, but in the PVD method, it is difficult to stably form an oxide of Al and accordingly, a hard coating layer consisting of Al oxide formed by the PVD method has not been put to practical use. On the other hand, in the hard coating layer consisting of carbides, nitrides or carbonitrides of Ti, Hf or Zr formed by the present PVD method, the wear resistance cannot be said sufficient and in the high speed cutting, in particular, cutting tools or wear resistance tools thereof have shortened lives because of poor wear resistance.

Under the situation, the present invention has been made for the purpose of providing a surface-coated hard material for a cutting tool or wear resistance tool having more excellent wear reisistance than that of the prior art with maintaining the substrate strength of the cutting tool or wear resistance tool, in particular, exhibiting excellent wear resistance in the high speed cutting. Disclosure of The Invention

In order to achieve the above described object, in the surface-coated hard material of the present invention, there is provided (1) a coating layer having such a functional gradient composition that the composition is changed by stages or continuously from TiN of the boundary with the substrate to TiAlN of the outer surface at the opposite side to the substrate on the surface of a cutting tool or wear resistance tool, (2) a hard coating layer having a thickness of 0.5 to 10 µm and consisting of at least one member selected from the group consisting of carbides, nitrides and carbonitrides of $Zr_{1-x} Al_x$ ($0 \leqq x \leqq 0.5$) such that the composition ratio of Zr and Al is changed in stages or continuously from Zr of the boundary with the substrate to ZrAl of the outer surface at the opposite side to the substrate on the surface of a cutting tool or wear resistance tool, and (3) a hard coating layer having a thickness of 0.5 to 10 µm and consisting of at least one member selected from the group consisting of carbides, nitrides and carbonitrides of $Hf_{1-x} Al_x$ ($0 \leqq x \leqq 0.5$) such that the composition ratio of Hf and Al is changed in stages or continuously from Hf of the boundary with the substrate to HfAl of the outer surface at the opposite side to the substrate on the surface of a cutting tool or wear resistance tool.

That is, the present invention provides a surface-coated hard material for a cutting tool or wear resistance tool characterized by providing a hard coating layer having a thickness of 0.5 to 10 µm and consisting of at least one member selected from the group consisting of carbides, nitrides and carbonitrides of $M_{1-x} Al_x$ (M represents Ti, Zr or Hf and $0 \leqq x \leqq 0.5$) such that the composition ratio of M and Al is changed in stages or continuously from M of the boundary with the substrate to MAl of the outer surface at the opposite side to the substrate on the surface of a cutting tool or wear resistance tool.

The hard coating layer can be provided on the whole surface of a cutting tool or wear resistance tool or only the surface of an edge part. Formation of the hard coating layer can be carried out in known manner, but the PVD method such as sputting methods, ion plating methods, etc. is preferable in respect of that the substrate strength can readily be maintained.

In the present invention, the hard coating layer is composed of at least one of carbides, nitrides and carbonitrides of $M_{1-x} Al_x$ ($0 \leqq x \leqq 0.5$) such that the composition ratio of M and Al is gradient from the boundary with the substrate to the surface opposite to the substrate. That is, th concentration of Al is increased continuously or in stages from the boundary with the substrate to the surface of the hard coating layer in such a manner that $x = 0$ at the boundary with the substrate and $x = 0.5$ at the surface opposite to the substrate in the abov describ d formula.

Since the boundary with the substrate is composed of a carbide, nitride or carbonitride of M, in particular, excellent in bonding strength, the hard coating layer is very excellent in stripping resistance. At the same time, the surface of the hard coating layer is composed of a carbide, nitride or carbonitride of MAl more excellent in wear resistance as well as melt adhesion resistance, so that it is capable of maintaining an excellent cutting property for a long period of time as a cutting tool or wear resistance tool.

Furthermore, it is found that in the surface-coated hard material provided with the above described hard coating layer, as a cutting tool or wear resistance tool, a very small amount of $Al_2O_3$ having a very high hardness at a high temperature is formed in the hard coating layer and accordingly, the tool exhibits a good wear resistance even in the high speed cutting.

The above described functional gradient composition of the hard coating layer can be changed in stages or continuously, but the latter case is preferable, since the stain due to difference of the coefficients of linear expansion is moderated. The layer thickness of the hard coating layer is in the range of 0.5 to 10 $\mu$m, since if less than 0.5 $\mu$m, the wear resistance is hardly improved, while if more than 10 $\mu$m, the breaking resistance is lowered.

In the above described formula, $M_{1-x}$ $Al_x$, the upper limit of x should be 0.5 since increase of Al in the hard coating layer to exceed $x = 0.5$ results in lowering of the hardness of the whole coating layer.

Examples

The present invention will now be illustrated in greater detail by Examples and Comparative Examples.

Example 1

Using a cutting insert made of a cemented carbdie with a composition of JIS standard P 30 (specifically, WC-20 wt % TiC-10 wt % Co) and a form of JIS SNG 432 as a substrate, the surface thereof was coated with each of coating layers having functional gradient compositions as shown in the following Table 2 by an ion plating method using vacuum arc discharge, as described below.

Namely, the above described cutting insert and Al and Ti as a target were arranged in a film making apparatus, in which the insert was then maintained in an Ar gas atmosphere with a vacuum degree of $1 \times 10^{-2}$ torr, rinsed by applying a voltage of -2000 V and heated at 500° C, after which the Ar gas was exhausted. While introducing one or both of $N_2$ gas and $CH_4$ gas at a rate of 300 cc/min into the film making apparatus, the Ti target was evaporated and ionized by vacuum arc discharge to coat the surface of the cutting insert with a carbide, nitride or carbonitride of Ti. Furthermore, various hard coating layers were formed by evaporating and ionizing the Ti target and simultaneously the Al target and controlling the composition ratio of Ti and Al so that the Al concentration was continuously increased and the composition on the surface was a carbide, nitride or carbonitride of TiAl.

For comparison, the surface of a cutting insert with the same composition and same form as described above was coated with the coating layers of carbide, nitride or carbonitride of Ti by an ion plating method using the same film-making apparatus and vacuum arc discharge as described above, thereby obtaining samples of surface-coated cutting inserts of the prior art as shown in Table 2. In addition, samples of coated cutting inserts were prepared in which coating layers of carbide of Ti, etc. shown in Table 2 were formed on the surface of the cutting insert with the same composition and same form by ordinary CVD method.

Each of the samples of the surface-coated cutting inserts prepared as described above was subjected to a continuous cutting test and intermittent cutting test under conditions as shown in Table 1 to measure the flank wear width of the edge, thus obtaining resuts as shown in Table 3.

Table 1

| | Continuous Cutting Test | Intermittent Cutting Test |
|---|---|---|
| Workpiece | SCM 435 | SCM 435 |
| Cutting Speed | 220 m/min | 220 m/min |
| Feed | 0.37 mm/rev | 0.30 mm/rev |
| Cutting Depth | 2.0 mm | 1.5 mm |
| Cutting Time | 15 min | 20 min |

Table 2

| Sample | Forming Method | Composition and Thickness of Hard Coating layer ($\mu m$) | | | | |
|---|---|---|---|---|---|---|
| | Method | Boundary Layer | | Intermediate Layer | | Surface Layer |
| 1 | PVD | | | $(Ti_{1-x}Al_x)N$ | | (4) |
| | | x = 0 | ⇒ | continuously changed | ⇒ | x = 0.5 |
| 2 | PVD | | | $(Ti_{1-x}Al_x)C_{1-y}N_y$ | | (4.5) |
| | | x = 0:y = 0 | ⇒ | continuously changed | ⇒ | x = 0.5: y = 0.5 |
| 3 | PVD | | | $(Ti_{1-x}Al_x)C_yN_{1-y}$ | | (5.5) |
| | | x = 0:y = 0 | ⇒ | continuously changed | ⇒ | x = 0.5: y = 0.5 |
| 4 | PVD | | | $(Ti_{1-x}Al_x)C_{0.5-y}N_{y+0.5}$ | | (5.0) |
| | | x = 0:y = 0 | ⇒ | continuously changed | ⇒ | x = 0.5: y = 0.5 |
| 5 | PVD | | | $(Ti_{1-x}Al_x)C_{y+0.5}N_{0.5-y}$ | | (5.5) |
| | | x = 0:y = 0 | ⇒ | continuously changed | ⇒ | x = 0.5: y = 0.5 |
| 6 | PVD | | | $(Ti_{1-x}Al_x)C_yN_{1-y}$ | | (6.0) |
| | | x = 0:y = 0 | ⇒ | continuously changed | ⇒ | x = 0.5: y = 1 |
| 7 | PVD | | | $(Ti_{1-x}Al_x)C_{1-y}N_y$ | | (5.0) |
| | | x = 0:y = 0 | ⇒ | continuously changed | ⇒ | x = 0.5: y = 1 |
| Prior Art | | | | | | |
| 8 | PVD | TiN 1 | | TiCN 2 | | TiN 1 |
| 9 | PVD | TiN 1 | | TiCN 1 | | TiN 2 |
| 10 | PVD | - | | - | | TiN 4 |
| 11 | CVD | - | | TiC 3 | | TiN 2 |
| 12 | CVD | TiN 2 | | $Al_2O_3$ 1 | | TiN 0.5 |

(Note) : Sample Nos. 8, 9, 10 and 12: for comparison

Other Samples: present invention

Table 3

| Sample No. | Flank Wear Width (mm) | |
|---|---|---|
| | Continuous Cutting | Intermittent Cutting |
| 1 | 0.130 | 0.100 |
| 2 | 0.120 | 0.110 |
| 3 | 0.115 | 0.110 |
| 4 | 0.110 | 0.105 |
| 5 | 0.120 | 0.110 |
| 6 | 0.115 | 0.120 |
| 7 | 0.110 | 0.115 |
| 8 | 0.300 | 0.210 |
| 9 | 0.205 | 0.180 |
| 10 | 0.410 | 0.250 |
| 11 | 0.205 | broken |
| 12 | 0.110 | broken |

It is apparent from the above described results that the samples of the coated cutting inserts of the present invention have both an excellent wear resistance and breakage resistance, i.e. more excellent cutting performance than the comaprative samples in both the continuous cutting and intermittent cutting tests.

Example 2

Using a cutting insert made of a cemented carbdie with a composition of JIS standard P 30 (specifically, WC-20 wt % TiC-10 wt % Co) and a form of JIS SNG 432 as a substrate, the surface thereof was coated with each of hard coating layers as shown in the following Table 4 by an ion platingmethod using vacuum arc discharge, as described below, to obtain a sample of surface-coated cutting insert of the present invention.

Namely, the above described cutting insert and Al and Zr as a target were arranged in a film making apparatus, in which the insert was then maintained in an Ar gas atmosphere with a vacuum degree of 1 x 10 $^{-2}$ torr, rinsed by applying a voltage of -2000 V and heated at 500 °C, after which the Ar gas was exhausted. While introducing one or both of $N_2$ gas and $CH_4$ gas at a rate of 300 cc/min into the film making apparatus, the Zr target was evaporated and ionized by vacuum arc discharge to coat the surface of the cutting insert with a carbide, nitride or carbonitride of Zr. Subsequently, various hard coating layers were formed by evaporating and ionizing the Al target and controlling the composition ratio of Zr and Al so that the Al concentration was continuously increased and the composition on the surface was a carbide, nitride or carbonitride of ZrAl.

Table 4

| Sample | Forming Method | Boundary Layer | | Intermediate Layer | | Surface Layer |
|---|---|---|---|---|---|---|
| | | Composition and Thickness of Hard Coating layer ($\mu$m) | | | | |
| 13 | PVD | | | $(Zr_{1-x}Al_x)N$ | | (4.0) |
| | | x = 0 | ⇒ | continuously changed | ⇒ | x = 0.5 |
| 14 | PVD | | | $(Zr_{1-x}Al_x)C$ | | (4.5) |
| | | x = 0 | ⇒ | continuously changed | ⇒ | x = 0.5 |
| 15 | PVD | | | $(Zr_{1-x}Al_x)CN$ | | (4.0) |
| | | x = 0 | ⇒ | continuously changed | ⇒ | x = 0.5 |
| 16 | PVD | | | $(Zr_{1-x}Al_x)C_{1-y}N_y$ | | (5.5) |
| | | x = 0:y = 0 | ⇒ | continuously changed | ⇒ | x = 0.5: y = 0.5 |
| 17 | PVD | | | $(Zr_{1-x}Al_x)C_yN_{1-y}$ | | (5.0) |
| | | x = 0:y = 0 | ⇒ | continuously changed | ⇒ | x = 0.5: y = 0.5 |
| 18 | PVD | | | $(Zr_{1-x}Al_x)C_{0.5-y}N_{y+0.5}$ | | (4.5) |
| | | x = 0:y = 0 | ⇒ | continuously changed | ⇒ | x = 0.5: y = 0.5 |
| 19 | PVD | | | $(Zr_{1-x}Al_x)C_{y+0.5}N_{0.5-y}$ | | (6.0) |
| | | x = 0:y = 0 | ⇒ | continuously changed | ⇒ | x = 0.5: y = 0.5 |
| 20 | PVD | | | $(Zr_{1-x}Al_x)C_yN_{1-y}$ | | (4.5) |
| | | x = 0:y = 0 | ⇒ | continuously changed | ⇒ | x = 0.5: y = 1 |
| 21 | PVD | | | $(Zr_{1-x}Al_x)C_{1-y}N_y$ | | (4.0) |
| | | x = 0:y = 0 | ⇒ | continuously changed | ⇒ | x = 0.5: y = 1 |

Each of the samples of the surface-coated cutting inserts prepared as described above was subjected to a continuous cutting test and intermittent cutting test under conditions as shown in Table 1 to measure the flank wear width of the edge, thus obtaining resuts as shown in Table 5.

Table 5

| Sample No. | Flank Wear Width (mm) | |
|---|---|---|
| | Continuous Cutting | Intermittent Cutting |
| 13 | 0.128 | 0.101 |
| 14 | 0.118 | 0.114 |
| 15 | 0.125 | 0.105 |
| 16 | 0.108 | 0.098 |
| 17 | 0.112 | 0.100 |
| 18 | 0.105 | 0.098 |
| 19 | 0.110 | 0.105 |
| 20 | 0.115 | 0.110 |
| 21 | 0.105 | 0.102 |

It is apparent from the above described results that of the samples of the surface-coated cutting inserts of the prior art, Sample Nos. 8-10 whose hard coating layers were formed by the PVD method were inferior in wear resistance and Sample Nos. 11 nd 12 whose hard layers were formed by the CVD method exhibited lowering of the breakage resistance due to deterioration of the toughness of the substrate, while Sample Nos. 13-21 of the surface-coated cutting inserts according to the present invention showed more excellent wear resistance in both the continuous cutting and intermittent cutting tests and since the hard coating layer was formed by the PVD method, the toughness of the substrate was maintained resulting in more excellent breakage resistance.

Example 3

Using a cutting insert made of a cemented carbdie with a composition of JIS standard P 30 (specifically, WC-20 wt % TiC-10 wt % Co) and a form of JIS SNG 432 as a substrate, the surface thereof was coated with each of hard coating layers as shown in the following Table 6 by an ion platingmethod using vacuum arc discharge, as described below, to obtain Sample Nos. 22 to 30 of the surface-coated cutting inserts of the present invention.

Namely, the above described cutting insert and Al and Hf as a target were arranged in a film making apparatus, in which the insert was then maintained in an Ar gas atmosphere with a vacuum degree of 1 x 10 $^{-2}$ torr, rinsed by applying a voltage of -2000 V and heated at 500°C, after which the Ar gas was exhausted. While introducing one or both of $N_2$ gas and $CH_4$ gas at a rate of 300 cc/min into the film making apparatus, the Hf target was evaporated and ionized by vacuum arc discharge to coat the surface of the cutting insert with a carbide; nitride or carbonitride of Hf. Subsequently, various hard coating layers were formed by evaporating and ionizing the Al target and controlling the composition ratio of Hf and Al so that the Al concentration was continuously increased and the composition on the surface was a carbide, nitride or carbonitride of HfAl.

Table 6

| Sample | Forming Method | Composition and Thickness of Hard Coating layer ($\mu$m) | | |
|---|---|---|---|---|
| | | Boundary Layer | Intermediate Layer | Surface Layer |
| 22 | PVD | | $(Hf_{1-x}Al_x)N$ | (4.0) |
| | | x = 0 ⇒ | continuously changed ⇒ | x = 0.5 |
| 23 | PVD | | $(Hf_{1-x}Al_x)C$ | (4.5) |
| | | x = 0 ⇒ | continuously changed ⇒ | x = 0.5 |
| 24 | PVD | | $(Hf_{1-x}Al_x)CN$ | (5.5) |
| | | x = 0 ⇒ | continuously changed ⇒ | x = 0.5 |
| 25 | PVD | | $(Hf_{1-x}Al_x)C_{1-y}N_y$ | (5.0) |
| | | x = 0:y = 0 ⇒ | continuously changed ⇒ | x = 0.5: y = 0.5 |
| 26 | PVD | | $(Hf_{1-x}Al_x)C_yN_{1-y}$ | (4.5) |
| | | x = 0:y = 0 ⇒ | continuously changed ⇒ | x = 0.5: y = 0.5 |
| 27 | PVD | | $(Hf_{1-x}Al_x)C_{0.5-y}N_{y+0.5}$ | (5.5) |
| | | x = 0:y = 0 ⇒ | continuously changed ⇒ | x = 0.5: y = 0.5 |
| 28 | PVD | | $(Hf_{1-x}Al_x)C_{y+0.5}N_{0.5-y}$ | (6.0) |
| | | x = 0:y = 0 ⇒ | continuously changed ⇒ | x = 0.5: y = 0.5 |
| 29 | PVD | | $(Hf_{1-x}Al_x)C_yN_{1-y}$ | (5.0) |
| | | x = 0:y = 0 ⇒ | continuously changed ⇒ | x = 0.5: y = 1 |
| 30 | PVD | | $(Hf_{1-x}Al_x)C_{1-y}N_y$ | (4.0) |
| | | x = 0:y = 0 ⇒ | continuously changed ⇒ | x = 0.5: y = 1 |

Each of the samples of the surface-coated cutting inserts prepared as described above was subjected to a continuous cutting test and intermittent cutting test under conditions as shown in Table 1 to measure the flank wear width of the edge, thus obtaining resuts as shown in Table 7.

Table 7

| Sample No. | Flank Wear Width (mm) | |
|---|---|---|
| | Continuous Cutting | Intermittent Cutting |
| 22 | 0.131 | 0.095 |
| 23 | 0.129 | 0.092 |
| 24 | 0.125 | 0.090 |
| 25 | 0.120 | 0.092 |
| 26 | 0.122 | 0.090 |
| 27 | 0.118 | 0.085 |
| 28 | 0.120 | 0.090 |
| 29 | 0.117 | 0.085 |
| 30 | 0.119 | 0.087 |

It is apparent from the above described results that of the samples of the surface-coated cutting inserts of the prior art, Sample Nos. 8-10 whose hard coating layers were formed by the PVD method were inferior in wear resistance and Sample Nos. 11 nd 12 whose hard layers were formed by the CVD method exhibited lowering of the breakage resistance due to deterioration of the toughness of the substrate, while Sample Nos. 22-30 of the surface-coated cutting inserts according to the present invention showed more excellent wear resistance in both the continuous cutting and intermittent cutting tests and since the hard coating layer was formed by the PVD method, the toughness of the substrate was maintained resulting in more excellent breakage resistance. Utility and Possibility

According to the present invention, there can be provided a surface-coated hard material for a cutting tool or wear resistance tool having more excellent wear reisistance than that of the prior art with maintaining the substrate strength of the cutting tool or wear resistance tool, in particular, being capable of maintaining good cutting performances, as a cutting tool or wear resistance tool, for a long period of time even in the high speed cutting.

## Claims

1. A surface-coated hard material for a cutting tool or wear resistance tool characterized by providing a hard coating layer having a thickness of 0.5 to 10 $\mu$m and consisting of at least one member selected from the group consisting of carbides, nitrides and carbonitrides of $M_{1-x}Al_x$ (M represents Ti, Zr or Hf and $0 \leqq x \leqq 0.5$) such that the composition ratio of M and Al is changed in stages or continuously from M of the boundary with the substrate to MAl of the outer surface at the opposite side to the substrate on the surface of a cutting tool or wear resistance tool.

# INTERNATIONAL SEARCH REPORT

International Application No PCT/JP90/01257

**I. CLASSIFICATION OF SUBJECT MATTER** (if several classification symbols apply, indicate all) [6]

According to International Patent Classification (IPC) or to both National Classification and IPC

Int. $Cl^5$ C23C14/06

**II. FIELDS SEARCHED**

Minimum Documentation Searched [7]

| Classification System | Classification Symbols |
|---|---|
| IPC | C23C14/00, 14/06 |

Documentation Searched other than Minimum Documentation to the Extent that such Documents are Included in the Fields Searched [8]

| | |
|---|---|
| Jitsuyo Shinan Koho | 1930 - 1990 |
| Kokai Jitsuyo Shinan Koho | 1971 - 1990 |

**III. DOCUMENTS CONSIDERED TO BE RELEVANT** [9]

| Category * | Citation of Document, [11] with indication, where appropriate, of the relevant passages [12] | Relevant to Claim No. [13] |
|---|---|---|
| X | JP, A, 63-255358 (Siemens AG), October 21, 1988 (21. 10. 88), Line 5, left column to line 4, right column, page 1 and line 18, lower left column to line 14, lower right column, page 3 & EP, A2, 881,005 & US, A, 4,842,710 | 1 |
| A | JP, A, 62-56565 (Mitsubishi Metal Corp.), March 12, 1987 (12. 03. 87), Lines 5 to 9, left column, page 1 (Family: none) | 1 |

* Special categories of cited documents: [10]

"A" document defining the general state of the art which is not considered to be of particular relevance

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**IV. CERTIFICATION**

| Date of the Actual Completion of the International Search | Date of Mailing of this International Search Report |
|---|---|
| December 12, 1990 (12. 12. 90) | December 25, 1990 (25. 12. 90) |
| **International Searching Authority** | **Signature of Authorized Officer** |
| Japanese Patent Office | |